Mid-frequency Sound Propagation, Reverberation, and Geoacoustic Inversion in Shallow Water

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LONG-TERM GOALS

The long-term goals of this work are (1) to use propagation or reverberation data to extract sediment geoacoustic parameters that can then be used to predict long range reverberation in shallow water; and (2) to validate such remote sensing techniques for geoacoustic inversion and their uncertainties using localized sediment ground truth measurements.

OBJECTIVES

The objectives of this effort are

1. to invert for geoacoustic parameters using bottom loss data from SW06 at mid-frequencies and compare with direct measurements and other geoacoustic inversion work from SW06;
2. to investigate the characteristics of wind-generated sea surface waves and model them for sound propagation predictions using surface wave data from ASIAEX;
3. to extend the reverberation model based on normal modes to 3-D geometries using both Monte Carlo method and scattering cross-sections.

APPROACH

The acoustic/ocean data sets and models, which are directly related to the objectives of this effort, are listed as follows.

1. Acoustic and ocean data

An 8 km towed source data were collected on Aug. 19 during SW06 in the frequency band of 1 – 10 kHz. Data were used to obtain bottom loss which was then used to infer sediment geoacoustic parameters.

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Oceanographic data were collected by a cluster of PO moorings (thermistor chains, CTDs, IW tracking, P/S/T/ADCP moorings, etc.) to provide supporting environmental data for modeling purposes. Directional surface wave spectrum data, taken from ASIAEX 2001 using a surface wave buoy, were used to study the characteristics of wind-generated sea surface waves. Original data were kindly provided by Peter H. Dahl (APL-UW).

2. Models used

Both PE and normal mode propagation models were used for modeling purposes. In addition, a normal mode code developed by Henyey et al. at APL-UW [1] was used for modeling reverberation due to bottom roughness (Yang et al., 2008). The APL normal mode code not only includes the trapped modes but also the leaky and continuum modes for short time behavior.

WORK COMPLETED

1. Inversion of geoacoustic parameters using bottom loss data from SW06 at mid-frequencies and comparison with direct measurements and other geoacoustic inversion work from SW06, in collaboration with Darrell R. Jackson and Dajun Tang (APL-UW)
2. Investigation of the characteristics of wind-generated sea surface waves and potential guidance to choose an appropriate surface wave spectrum model for acoustic modeling purposes, in collaboration with Ji-Xun Zhou and Peter H. Rogers (Georgia Institute of Technology)
3. Development of a normal mode based reverberation simulation capability for 3-D geometries to model boundary scattering, in collaboration with Dajun Tang and Eric I. Thorsos.

RESULTS

Geoacoustic inversion using bottom loss data at mid-frequencies from SW06

Mid-frequency acoustic data taken from SW06 along a tow track (0.1—8.1 km) were used to obtain bottom loss which was then used to invert for sediment geoacoustic parameters. The inverted sediment sound speed was compared with direct measurements and geoacoustic inversion results using different methods in SW06 within a 2 km boxed area. The GPS plot for all measurements is shown in Fig. 1(a) and the sediment sound speed results are shown in (b). The three direct measurements used different instruments and they are Sediment Acoustic-speed Measurement System (SAMS, APL-UW), ISSAP (Mayer & Kraft, U of New Hampshire), and geo probe (Turgut, NRL). The penetration depths of SAMS, ISSAP, and geo probe were 1.6 m, 20 cm, and 30 cm and measurements were carried out at 2 – 20, 65, and 20 kHz. The three inversion results are the one from this work, work from Jiang et al and Choi et al respectively. The three inversion results were obtained from short range propagation data in the frequency band of 2 – 5, 1.5 – 4.5, and 1 – 20 kHz respectively. Of the three direct measurement results, the ones using SAMS and geo probe are within the same uncertainty bound. Two of the inversion results, from Jiang et al and Choi et al, are in consistent comparison with them. In addition, all four measurements as shown in Fig. 1(a) are in close vicinity. For the other two results, i.e. the direct measurement result using ISSAP and inversion result of this work stand high in their own group. Note that the ISSAP works at 65 kHz and if accounting for 3% of dispersion (Williams et al, 2002) between 65 kHz and 3 kHz, the result would fall into similar range as this work. The discrepancy between four measurements with lower values and the other two, considering their geographical

locations, indicates spatial variation of sediment properties. Substantial spatial variation in sediment sound speed has been reported in this area through the ONR-sponsored Geoclutter program (Goff et al).

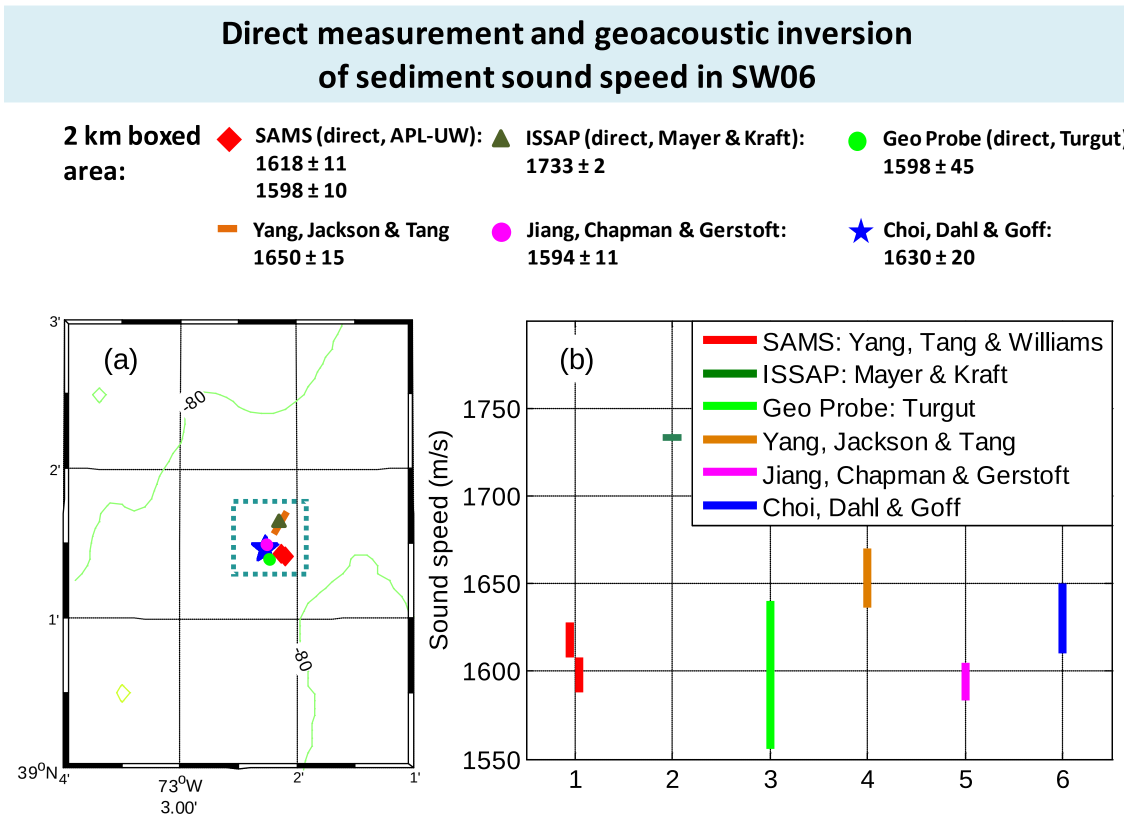

Figure 1 Comparison of sediment sound speed between direct measurements and geoacoustic inversion results in SW06.

Modeling of wind-generated sea surface waves with applications to acoustics

A quantitative description of the sea surface is necessary for studying its acoustical effect on shallow water sound propagation. During the Asia Seas International Acoustics Experiment (ASIAEX) in the East China Sea (ECS), nine days of consecutive wind velocity and directional wave spectrum data were recorded. These data were analyzed to show the characteristics of wind-generated surface waves in shallow water. Existing surface spectrum models were compared with the ASIAEX data to find out which model gives the best prediction of the RMS surface waveheight in the coastal region. The JONSWAP-Mitsuyasu model showed relatively better fit to the ASIAEX RMS waveheight data. All models deviated the experimental when the wind input measure, wave age U/cp (U: wind speed; cp: wave speed at its peak frequency), is small or with swell component. Using wave age U/cp as a sorting parameter, it was found that a combined Mitsuyasu-Donelan model can make a better RMS surface waveheight prediction. The results of this work may be beneficial for acoustic propagation and scattering modeling; wave age can be used as a sorting parameter to find the most appropriate surface model to use for acoustic predictions.

Development of a 3-D reverberation simulation capability for boundary scattering

A normal mode based reverberation model has been developed to study reverberation intensity due to bottom roughness using first-order perturbation theory. Bottom roughness scattering is treated through a Monte Carlo method based on scattering from rough bottom. This reverberation model has been extended to use scattering cross-sections to treat boundary scattering in 3-D geometries. The Reverberation Modeling Workshop (RMW) problem solutions provide ideal benchmarks for validating the accuracy of the reverberation code here. As it happened, the result of this work has helped clarify an important modeling issue in the RMW simulation work which is the discrepancy between solutions based on modes and those based on rays. There has been considerable effort expended to understand which of these subfamily solutions is correct. These comparisons showed that the approach used in the original mode solutions was not accurate for high bottom loss case. That approach was based on the commonly used method of incorporating the bottom loss into a modification of the imaginary parts of the horizontal mode wave numbers, but to make no change in the mode functions themselves, i.e., to use unperturbed modes. The solutions of this model incorporated the bottom loss into a modification of both the horizontal mode wave numbers and the mode functions. This leads to solutions for this case that are in much better agreement with rays solutions.

IMPACT/APPLICATIONS

Direct measurement of sediment geoacoustic properties VS inversion results

Direct measurement should provide ground truth for inversion results. For fair comparison with inversion, which represents averaged sediment properties over the acoustic path, multiple direct measurements along the same acoustic path should be made to provide reliable statistics and compare with inversion results. The work completed here is helpful for future experimental planning with the potential of using SAMS to assess the spatial variability of sediment properties and to provide validation for geoacoustic inversion models.

Mid-frequency sound propagation and geoacoustic inversion

Limited inversion work has been done in the frequency range of 2-10 kHz and therefore the work here can be valuable to others in the community. In addition, for sound propagation and geoacoustic inversion, usually forward scattering is not taken into account. It has been oberseved in this work that forward scattering from topographical changes is important at mid-frequencies. To successfully model the acoustics, the environmental sampling, i.e. bottom topography in this case, should be done to the accuracy of several centimeters at these frequencies.

Modeling of wind-generated sea surface waves with application to acoustics

The conclusions of this work are based on a limited 9-day directional surface wave spectrum data set and need to be confirmed by more observations. The results of this work, however, may be beneficial for acoustic propagation and scattering modeling; wave age can be used as a sorting parameter to find the most appropriate surface model to use for acoustic predictions.

Reverberation modeling

There are various simulation methods for reverberation modeling with varying degrees of accuracy. This mode based reverberation model can be used to investigate differences between reverberation models that are based on normal mode and ray theory. It can also be used to study the sensitivity of various environmental parameters and use gained knowledge as guidance for future experiments.

RELATED PROJECTS

The reverberation modeling work has been conducted in collaboration with Dajun Tang and Eric I. Thorsos at APL-UW for the Reverberation Modeling Workshop funded by ONR. http://ftp.ccs.nrl.navy.mil/pub/ram/RevModWkshp_II

The reverberation modeling work has been conducted in collaboration with Eric I. Thorsos at APL-UW for Transport Theory for Propagation and Reverberation funded by ONR (N00014-10-1-0333).

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